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Photoionized Herbig-Haro objects in the Orion Nebula through deep high-spectral resolution spectroscopy II: HH 204

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ABSTRACT

Contribuciones de Will para el artículo

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1. MATERIAL DE WILL

1.1. *Sub-arcsecond imaging of HH 204*

Figure 2a shows the ratio of surface brightnesses $R([\mathrm{O\,III}]) = S([\mathrm{O\,III}]\ \lambda5007)/S(\mathrm{H}\alpha\ \lambda6563)$ calculated from *HST* WFPC2 observations in the F502N, F547M, F656N, and F658N filters from program GO5469 (O'Dell & Wong 1996). Flux calibration and correction for contamination by continuum and non-target lines was performed using the coefficients given in O'Dell (2009). It can be seen that the line ratio in the background nebula shows a pronounced gradient from $R([\mathrm{O\,III}]) \approx 0.3$ in the north-east to $R([\mathrm{O\,III}]) \approx 0.5$ in the south-west.[1] Inside the bow shock, the ratio is significantly smaller, for instance falling from $\simeq 0.4$ to $\simeq 0.2$ along the length of the UVES slit.

However, the most interesting feature of the $R([\mathrm{O\,III}])$ image is the slight *increase* in the ratio that is seen in a thin layer along the leading edge of the bow shock. This is most clearly visible in the northern wing of HH 204, such as the area highlighted by a dotted outline box in the figure. Average profiles across the shock for this region are shown in Figure 2b. The lower panel shows that the raw ratio (solid black line) increases only slightly above its value in the background nebula, which is because the brightness increase across the bow shock is only a small fraction of the background brightness, as can be appreciated in the upper panel. In order to isolate the behavior of the shocked component, we calculate the background-subtracted line ratio:

$$R'([\mathrm{O\,III}]) = \frac{S([\mathrm{O\,III}]) - S_{\mathrm{BG}}([\mathrm{O\,III}])}{S(\mathrm{H}\alpha) - S_{\mathrm{BG}}(\mathrm{H}\alpha)} \qquad (1)$$

under the assumption that S_{BG} for each line is constant along the profile. The result is shown as a gray histogram in the lower panel of the figure, which reveals a sharp peak of width ≈ 0.3 mpc that reaches a maximum value $R'([\mathrm{O\,III}]) \approx 2R_{\mathrm{BG}}([\mathrm{O\,III}])$ and is centered on a displacement of ≈ -0.1 mpc. The origin of the displacement axis is set to the peak in the spatial gradient of the Hα surface brightness, corresponding to the outer edge of the dense shocked shell. The negative displacement of the $R'([\mathrm{O\,III}])$ peak means that this occurs *outside* the dense shell, closer to the shock front itself.

Figure 2c shows the same quantities calculated along a cut that coincides with our UVES slit at the head of HH 204. In this case, $R'([\mathrm{O\,III}])$ is always significantly less than $R_{\mathrm{BG}}([\mathrm{O\,III}])$, but it does still show a small local peak with a position and width that is similar to the

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[1] For comparison with results from our UVES spectra, and using the average reddening for the HH 204 region (Weilbacher et al. 2015), the conversion is $\lambda4959/\mathrm{H}\beta \approx 1.1\lambda5007/\mathrm{H}\alpha$.

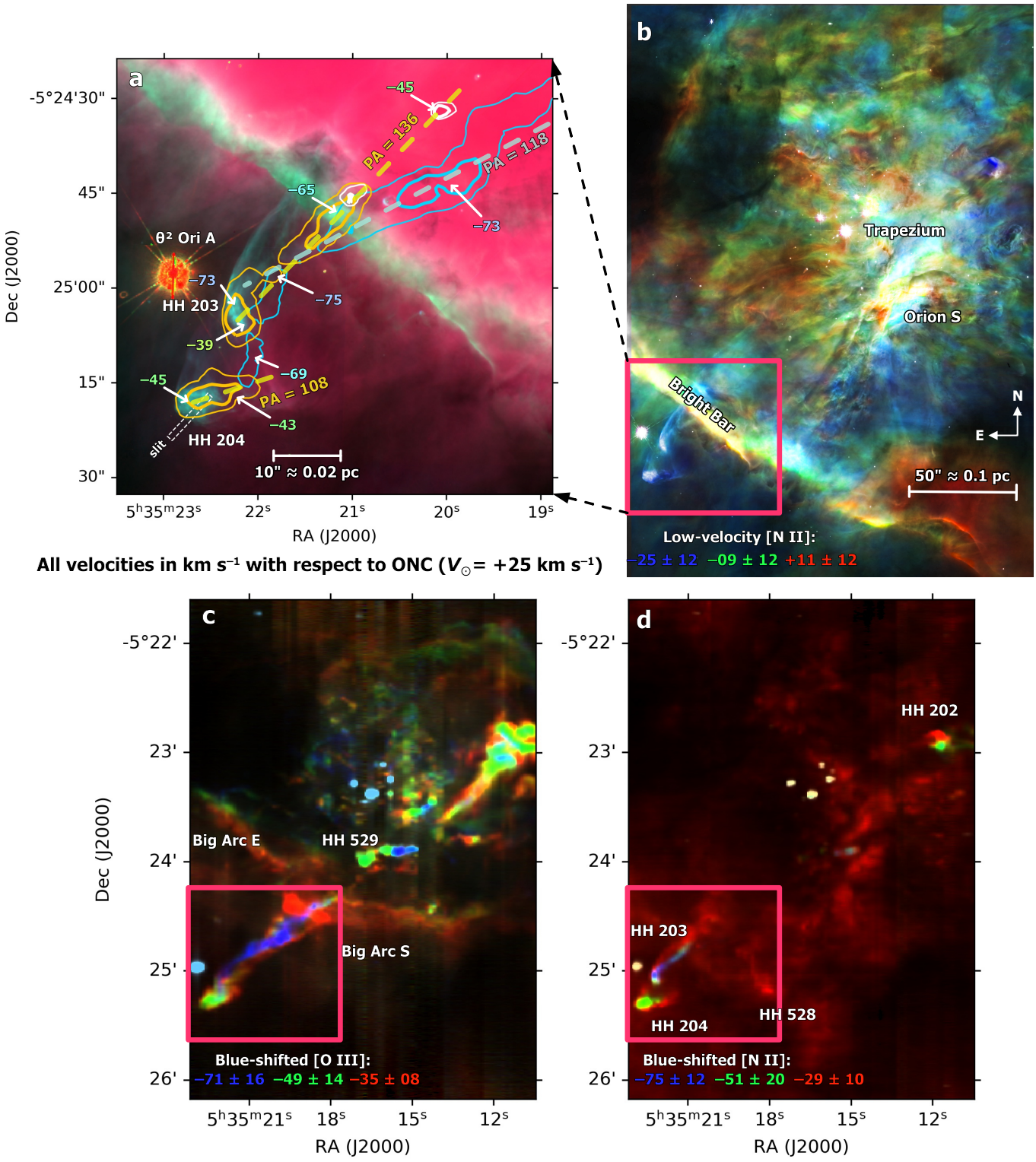

Figure 1. Finding chart.

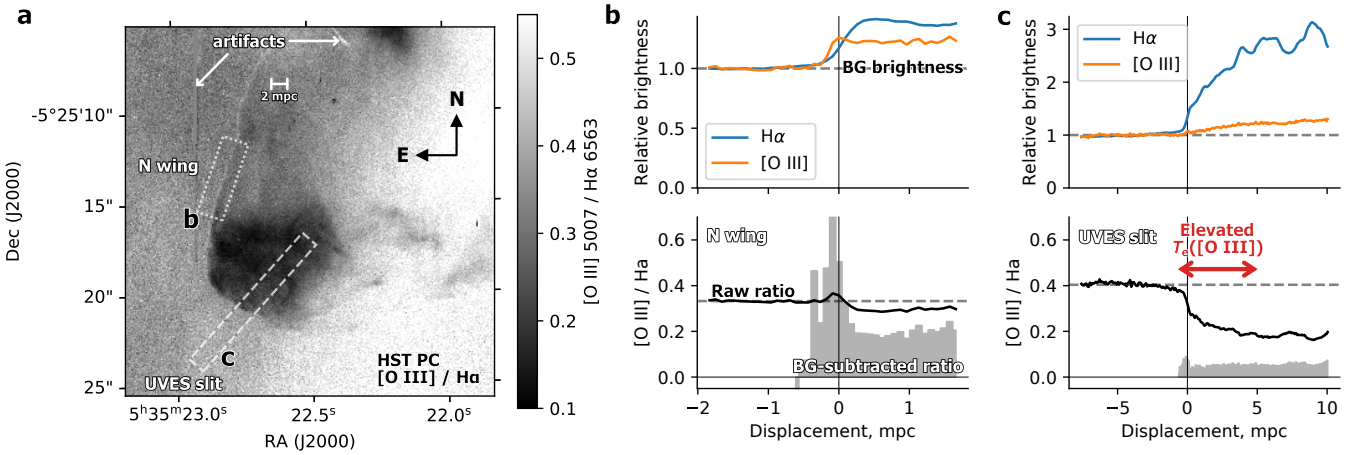

Figure 2. (a) Map of the line ratio [O III] λ5007/Hα λ6563, calculated from *HST* images with the PC chip of the WFPC2 camera. The position of the UVES spectrograph slit is outlined by a dashed box, while a further region of interest in the N wing of the bow shock is indicated by a dotted box. The vertically oriented "scar" at upper left is an artifact due to the bright star θ^2 Ori A, located just north of the field of view. (b) Average cut profiles of the *HST* images for the box in the N wing that is outlined in panel a. Upper graph shows surface brightness profiles in the two emission lines, normalized to the mean nebular background value outside of the shock. Lower graph shows the line ratio, with the raw ratio indicated by the black solid line and the background-subtracted ratio indicated by the gray histogram. The zero point of the displacement axis is taken to be the location of the maximum gradient in the Hα surface brightness. (c) Same as panel b, but showing average profiles of the *HST* images along the UVES slit. The region of the slit that shows T_e([O III]) > 12 000 K in the blueshifted component is indicated by the red arrow.

more impressive one in the northern wing. These peaks in $R'([\mathrm{O\,III}])$ occur over a much smaller scale than any of spatial gradients that we find in our UVES slit spectra and are only detectable because of the high spatial resolution of the *HST*.[2]

REFERENCES

O'Dell, C. R. 2009, PASP, 121, 428

O'Dell, C. R., & Wong, K. 1996, AJ, 111, 846

Weilbacher, P. M., Monreal-Ibero, A., Kollatschny, W., et al. 2015, A&A, 582, A114

[2] Pixel size of 0.045 arcsec, which well samples the PSF width at Hα of 0.083 arcsec.